CREATIVE UNDECIDABILITY OF REAL-WORLD DYNAMICS AND THE EMERGENT TIME HIERARCHY

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Abstract

The unreduced solution to the arbitrary interaction problem, absent in the standard theory framework, reveals many equally real and mutually incompatible system configurations, or "realizations". This is the essence of universal dynamic undecidability, or multivaluedness, and the ensuing causal randomness (unpredictability), non-computability, irreversible time flow (evolution, emergence), and dynamic complexity of every real system, object, or process. This creative undecidability of real-world dynamics provides causal explanations for "quantum mysteries", relativity postulates, cosmological problems, and the huge efficiency of high-complexity phenomena, such as life, intelligence, and consciousness, giving rise to extended applications, far beyond the critical limits of usual science paradigm.

Dynamic undecidability, chaoticity, non-computability, and complexity of any real interaction process, system, and object

Usual mathematical ideas around undecidability, unpredictability/randomness, and non-computability (e.g. Gödel's incompleteness theorems) consider the features of mathematical structures themselves, with only indirect or occasional links to real-world dynamical processes, which results in general references to fundamental limits of scientific (mathematically based) knowledge. They are used in the *negative*, restrictive context of *im*possibility, *in*explicability, or *in*completeness of a process, observed property, or theory (see e.g. [1]).

These features of usual concepts may be related to the fact that they do not rely on the consistent solution to the arbitrary, unreduced *interaction problem*, while it is those unreduced interaction processes that determine real-world dynamics and evolution. This arbitrary interaction problem is simply classified under another negative label of *non*integrability (or *in*solubility), without any special idea about the absent solution properties and character.

The unreduced interaction problem solution has been extensively analyzed within the *universal dynamic complexity concept*, including applications to systems of various complexity levels, from elementary particles to living, intelligent, and social systems [2-14]. These rigorously derived results show that the group of notions around undecidability and unpredictability can be provided with a *unified, reality-based, and creative meaning* leading to promising *applications*, beyond the *artificial* limits of usual description.

The arbitrary many-body interaction problem can be universally formulated in the Hamiltonian form generalizing the Schrödinger equation for quantum systems and the Hamilton-Jacobi equation for classical systems (we then confirm the absolute universality of this equation). This starting *existence equation* for the system state function (actually, in most cases, its density distribution function) simply describes the initial system configuration. It does not contain any formally inserted time variable, since time (as well as space) is an emergent entity in this description.

When we try to solve this "unsolvable" equation, it is important to avoid any usual simplification of the "mean-field" or other perturbative kind, since all dynamical links are important, as we confirm later, for the emergent interaction result. We use the standard problem transformation to a system of equations for the state function components in terms of eigenmodes of system elements. And then we apply the *generalized effective potential method* to reduce the system of equations to only one equation, the *effective existence equation*, but containing the complicated and dynamically rich *effective potential* [2-6].

At this *key point* of unreduced problem analysis, we show that due to the mentioned dynamical features of the unreduced effective potential, including its *dynamic nonlinearity*, the interaction process produces *many mutually incompatible* but *equally real* system configurations, or *realizations* (instead of *only one* such solution in any usual "model"), which are forced then to *permanently replace one another* in *dynamically random* order thus defined, under the influence of the main interaction, without any external "noise". This *dynamic redundance*, or *multivaluedness*, or *undecidability*, or *unpredictability*, phenomenon is rigorously derived thus for any generic, non-simplified interaction process.

While we refer to other papers [2-12] for mathematical details of this important conclusion (supported by both algebraic and graphical approaches), a simple illustration will be relevant here. Let us imagine two attractively interacting objects, each of them containing N loosely connected elements or eigenmodes, and let us consider only pair interaction between elements of different objects. If each element of one object interacts with each element of the other object, we obtain the total number of N^2 possible combinations of attracted elements, while we always have only N local configurations for their emergence. It means that those elements will be forced to jump between possible local combinations, thus forming $N_{\Re} = N$ system realizations changing in causally random order (with each realization remaining thus *dynamically unstable*). It should be clear that we obtain the same kind of result for any generic interaction, with its own realization number $N_{\Re}$ (it is determined, in general, by the number of combinations of interacting eigenmodes).

We can then provide the *universal definition of dynamic complexity* C of any system, process, or object as any growing function of its (interaction) realization number, or rate of their change, equal to zero for the unreal situation of only one realization (invariably considered in usual theory): $C = C(N_{\Re})$, $dC/dN_{\Re} > 0$, $C(1) = 0$ (e.g. $C = C_0 \ln N_{\Re}$ or $C = C_0(N_{\Re} - 1)$). Since realizations emerge and replace one another in causally random order, we obtain thus also the unified definition of *randomness/chaoticity*, with its *dynamic, a priori determined probabilities* ($\alpha_r = 1/N_{\Re}$ for each r-th elementary realization emergence). This truly dynamic chaoticity is essentially different from its inconsistent simulation in conventional, *dynamically single-valued*, or *unitary*, theory by "exponentially diverging trajectories", which needs

external noise, depends on observation time and extends incorrectly the perturbation theory validity range [2,3,6]. In addition, this *truly random* dynamics of any real interaction is *non-computable* par excellence, in the sense of usual, *regular* computation procedure, in contrast to basically regular, computable behaviour of any unitary model.

We see therefore that the *entire group* of related fundamental notions, including undecidability, unpredictability, uncertainty, randomness/chaoticity, non-computability, complexity, emergence, nonlinearity, and nonintegrability, are obtained simultaneously and naturally by the *mathematically complete* solution of the unreduced interaction problem underlying all *real-world* structure dynamics and evolution, with the *central role* of the above *dynamic undecidability*, or multivaluedness, phenomenon. We see also why such consistent and unified real-world description cannot be obtained in principle within any conventional, unitary theory: this latter kind of artificially and strongly reduced description looks for *only one* problem solution (system configuration) there, where we always have *many equally real* and therefore actually emerging and changing ones (cf. usual "solution uniqueness" theorems, appearing thus to be basically incomplete [2,3]).

One may wonder, however, how this allegedly universal picture of permanently chaotically moving reality correlates with observed rigid and quasi-stable structures or trajectories. The answer to this question involves the *unified classification of all possible regimes of multivalued (undecidable) system dynamics* [2-12]. If characteristic frequencies (or respective level spacings) of system dynamics, corresponding to inter-element and intra-element motions, have comparable values, we obtain a highly chaotic (visibly irregular) regime, with its ultimate case of *uniform, or global, chaos* for equal frequencies (because of strong "competition" between equally probable realizations with essentially different configurations).

In the opposite limit of essential difference between the characteristic frequencies, we obtain the *externally* quasi-ordered regime of *dynamically multivalued self-organization*, where the low-frequency motion of a rigid "shape" of an object "enslaves" many rapidly and *chaotically* changing internal realizations with very similar configurations. Since those internal system realizations are often organized in a multilevel (fractal) hierarchy, we also call this case *dynamically multivalued self-organized criticality (SOC)*. In contrast to usual theory, *every* externally ordered configuration contains a *truly random* realization change process, implying generalized *entropy growth* for *any*, even externally regular structure formation. All observed dynamic regimes are situated between those two limiting cases of uniform chaos and quasi-regular SOC, with the possibility of their clear quantitative identification and control based on the mentioned frequency ratio criterion.

Universal dynamic origin of time, emergence, and evolution

As described above, the qualitatively new, *intrinsically creative* role of the universal dynamic undecidability, or multivaluedness, of any real interaction dynamics is due to permanent *physical emergence* and *change* in causally random order of redundant system realizations, in the form of either visibly irregular or quasi-ordered dynamic regime. And since the initial interaction problem formulation is a timeless Hamiltonian equation, we arrive at the fundamental conclusion about the *physical, dynamic origin of time* (and the related phenomena of *emergence* and *evolution*) in this *dynamically undecidable realization change* process.

The unified definition of *elementary event* is naturally obtained as the fact and process of each next *realization emergence*. The *unceasing*, *interaction-driven* sequence of events of realization emergence (and replacement) forms the *dynamically obtained*, *intrinsically discrete (quantized)* and *irreversible* flow of time. *Dynamic time flow discreteness* is due eventually to the *holistic character* of unreduced interaction process (where everything interacts with everything else), which leads to well-defined, finite-size realization formation and change, while the *intrinsic irreversibility* of *complex-dynamical time flow* is due to c*ausally random, truly unpredictable choice* of each emerging system realization (dynamic undecidability being again the underlying key feature). One must emphasize this *intrinsic link* between the physically real, irreversible time flow and *genuine dynamic randomness* of underlying interaction dynamics. It explains, in particular, all the difficulties with the origin of time in usual, dynamically single-valued theory, with its inevitably postulated smooth growth of artificially inserted time variable.

Thus dynamically defined time flow is mathematically described by the *intensity of realization change process* measured as its *frequency*, $\nu = 1/\tau$, where the characteristic period of realization change $\tau = \Delta t$ determines the real time increment Δt. The latter can also be obtained as $\Delta t = \Delta x/\upsilon_0$, where υ_0 is the velocity of perturbation propagation in the material of relevant system components and $\Delta x = \lambda$ is the equally fundamentally defined *space element*, its *elementary length*, determined by the characteristic eigenvalue difference between neighbouring realizations [2-6].

As there are many interaction processes in nature (or even within each real object), one may argue that there should be as many separate time flows. This is true except that those individual time flows are not really separated and are organized instead in a hierarchy of levels of unreduced dynamic complexity of the world. This complexity or interaction hierarchy starts from the simplest possible, least structured interaction process (between two fundamental, effectively structureless protofields) that gives rise to *explicitly, dynamically emerging* structures of the first level (physically real elementary particles, see below), which, together with their equally dynamically emerging interactions, produce real world structures (e.g. atoms) of the next complexity level, and so on, till the highest known complexity levels of life, intelligence, and consciousness.

Since we have physically *real links* between *explicitly emerging* consecutive complexity levels and respective *causal origins* of every observed structure and property (as opposed to the popular idea of "more is different"), we also obtain the *naturally ordered hierarchy of time flow*, starting from the lowest, most universal and fine-grained, "fundamental-physics" time flow contained within progressively slower and more coarse-grained intrinsic time flows at higher complexity levels.

It is important that these levels of growing complexity (with ever higher total realization numbers) are obtained in the same unreduced interaction analysis by the generalized effective potential method, in the form of *dynamically probabilistic fractal* of the general interaction problem solution [3-5,8-12]. By contrast to usual, purely mathematical fractals, the dynamically probabilistic fractal of the complete interaction problem solution does not possess, in general, the simplified "self-similarity" kind of symmetry and displays, due to its explicit dynamic origin, permanent realization change in causally random order at each level

of fractal hierarchy. It is therefore a permanently probabilistically changing, "living" kind of structure, containing the respective time flow hierarchy and including eventually the *entire world dynamics* (now thus *naturally unified*).

This concept of emergent complex-dynamical time leads to the *universal* definition of the *state of rest and (global) motion* for any system at any complexity level. The *state of rest* corresponds to the most homogeneous (least structured) distribution of system realization probabilities with the minimum value of realization change frequency, proportional to the differential form of dynamic complexity known as total energy [2-6]. A *state of global motion* emerges as an inhomogeneous tendency in the realization probability distribution determining the direction of motion as the total complexity-energy grows above its minimum value in the state of rest.

It should be emphasized that even in the internally ordered dynamics of a state of motion, each system transition between its consecutive realizations occurs through the *causally random* realization choice, giving rise to the *universal and intrinsic property of inertia and inertial mass* proportional to the total complexity-energy (and being thus also a differential form of dynamic complexity) [2-6]. Indeed, the intense and dynamically random realization change process within any real particle or body will resist any attempt to change its state of global motion or rest by modifying its realization probability distribution.

One can discover then that this universal link between the time flow and motion (through causally random realization change) naturally leads to *causal (dynamic) relativity effects* unified with equally transparent and physically real *quantization features* (thus solving the problem of incompatibility of these two kinds of behaviour in conventional theory) [2-5]. Indeed, it is the *same* realization change process within any globally moving particle, body, or system that gives rise to *both intrinsic time flow and global motion*, and therefore any change of the latter implies inevitable, purely dynamic change of the former.

The detailed effects of special (and then general) relativity are *rigorously derived* in the cited papers, and despite their usual form, they now have a transparent *causal, dynamic origin* instead of formally imposed postulates of conventional relativity. The true, totally causal, and now *intrinsically unified* origin of both relativistic and quantum (dynamically discrete) effects appears to be hidden in the complex, *dynamically multivalued (undecidable)* behaviour of underlying *unreduced* interaction processes. Moreover, as we have the fractal hierarchy of complexity levels with their intrinsic time flows described above, we obtain the corresponding *multilevel hierarchy* of *generalized relativistic and quantum effects*, with interesting implications for particular systems [2-4].

While the emergent relativistic and quantum effects refer rather to system complexity evolution within one complexity level, greater changes of the same dynamic complexity are involved in transitions from lower to higher complexity levels. This generalized complexity transformation as the unified basis for any kind of real-world dynamics can be described as its change from the *latent, least structured form* of *dynamic information* (being the integral and generalised form of the "potential energy" of interaction) to the *explicit, unfolded form* of *dynamic entropy* (generalising the integral form of "kinetic energy"), so that the sum of both complexity forms, expressing the *total complexity* of a system, remains unchanged.

As the causally irreversible time flow described above determines the *unidirectional* complexity transformation from its latent, *always decreasing* form of dynamic information, expressed by *complexity-action* $\mathcal{A}$, to explicit, *always growing* form of *complexity-entropy* S, we obtain the *unified encompassing law* of *universal symmetry, or conservation and transformation, of complexity*: $C = \mathcal{A} + S = \text{const}$, $\Delta S = -\Delta\mathcal{A} > 0$, with C standing for the *total system complexity*. The generalized complexity-action $\mathcal{A}$ emerges as the unified integral measure of potential complexity form, which is expressed by the simplest linear combination of two basic complexity forms of emerging space and time, $\Delta\mathcal{A} = p\Delta x - E\Delta t$ (with the differential complexity measures of generalized momentum p and total energy E) [2-12].

This unified law of the symmetry of complexity determines every system dynamics and evolution and generalizes any correct fundamental law and dynamic equation, in particular, in its differential form, the *universal Hamilton-Jacobi-Schrödinger formalism*, which confirms the validity of the starting existence equation [2-12].

We see therefore how the unreduced interaction analysis, revealing the creative dynamic undecidability of real-world dynamics, leads to its *intrinsically unified and consistent picture*, without missing parts and unsolvable problems of artificially reduced, dynamically single-valued and timeless conventional framework. The latter obtains its well-specified definition and explanation as the *single-valued, effectively zero-dimensional (point-like) projection* of the dynamically multivalued reality, with the ensuing variation of the quality of more or less successful projection for each particular case, including various guesses around the notions of undecidability, unpredictability, non-computability, nonintegrability, and nonlinearity.

Thus, for example, Gödel's incompleteness theorems can now be extended in a constructive and realistic, though rather trivial, way as expression of inevitable links of each complexity level and system to its dynamic origins from lower and descendants at higher complexity levels. Those links cannot be avoided, but they are used for consistent derivation and understanding of progressively unfolding real-world complexity, as demonstrated above and confirmed below. The artificial and *maximum possible* incompleteness of unitary theory is thus extended to the *exact*, multivalued image of reality in the universal science of complexity.

Active nanobiosystems, reliable genetics, integral medicine, advanced artificial intelligence, and sustainable development without crises

The creative, *problem-solving* potential of dynamic undecidability and unpredictability introduced above is based on the underlying *unreduced* solution to the *real-world* interaction problem, whose efficiency is confirmed by various *applications* to emergent world structure description at different complexity levels [2-14].

Complex, dynamically undecidable interaction results start emerging at the lowest sublevels of real-world dynamics in the form of *physically real* elementary particles and all their intrinsic and dynamic properties (now *naturally unified*), including universally defined space and time, mass, electric charge, spin, unified fundamental interactions with their observed properties, all quantum and relativistic features (now explained without "mysteries" and formal postulates), and particle species spectrum without the "hierarchy problem" [2-6].

Note that the same creative undecidability features lead to the consistent framework of the *explicitly emergent cosmology picture* at all scales, where the severely reduced and *therefore contradictory* schemes of unitary cosmology are replaced by the *dynamically multivalued* structure-creation processes without any missing, or "dark", entities or dimensions [3-5].

Massive particles emerge as *chaotic quantum beat (self-oscillation) processes* in the simplest starting system of two homogeneous protofields uniformly attracted to each other, where the "hidden-variable" difficulties of unitary theory are naturally solved from the beginning by the *qualitatively extended, multivalued* character of unreduced interaction dynamics, with the resulting particle structures actually taking all their observed states in causally random order. The *physically real wavefunction* is rigorously obtained as the special "intermediate" realization with weak effective interaction magnitude, which is transiently taken by a quantum particle (or, in general, any system) during its permanent transitions between all other, "normal" realizations with strong interaction and concentrated structure.

Next higher-complexity levels emerge in interaction between elementary quantum particles in the form of causally complete versions of *quantum chaos* (for nondissipative, Hamiltonian interaction processes), *quantum measurement* (for slightly dissipative interaction cases), and *dynamic emergence of classical, permanently localised kind of behaviour* for elementary bound systems like atoms [2-6]. Here too, the stagnating problems of unitary theory are naturally solved due to the extended interaction dynamics, including the genuine dynamic randomness in purely quantum Hamiltonian systems (passing to classical chaos under usual quasi-classical transition), quantum measurement in quantum systems without mysteries, and classical behaviour emergence in closed systems, without any external "decoherence".

These causally complete versions of the three kinds of interaction processes at the level of interacting particles, atoms, and molecules lead to a great variety of promising applications in the extended, *complex-dynamical nanobiosystem design and control* closely related to life-science applications [6,7]. The key point here, inevitably ignored in the unitary science framework, is the *unavoidable* and *ubiquitous* presence of *strong dynamical chaos*, simply because of the lowest position of this complexity level, implying proximity to the strong-chaos limit in the unified frequency-resonance criterion of chaoticity mentioned above.

On one hand, this fundamental feature implies *impossibility of any unitary quantum machine operation*, such as conventional quantum computing, even in the total absence of noise. On the other hand, we obtain an even more promising compensation for this restriction, in the form of undecidable (chaotic) nanobiosystem operation showing the truly "magic" power in another way, due to the *exponentially huge efficiency* of unreduced interaction dynamics (in the suitable mixture of the above nanoscale interaction processes) [3,5-12]. This is the direct manifestation of the *creative power of dynamic undecidability and chaoticity* of real interaction processes, where the resulting interaction power is determined by the practically infinite, exponentially huge number of interacting mode combinations (system realizations), which explains the special, "magic" properties of life, intelligence, and consciousness.

We thus arrive at higher-level applications involving *complex-dynamical nanometal physics*, *active condensed matter*, *reliable genetics*, and *integral medicine* [3,6-9]. The first two ideas imply qualitatively new design of metal and condensed-matter physics objects and desired results: if conventional solid-state science deals with collective and bulk behaviour and

properties of big agglomerates of atoms and molecules (tending to weak-interaction cases), the new, "living" condensed-matter paradigm will study strong-interaction, explicitly complex-dynamic (chaotic) behaviour of individual (local) nanoscopic interaction cases in a larger solid-state matrix, providing a sort of "artificial living systems" able to reproduce the mentioned exponentially huge efficiency of unreduced interaction processes.

Reliable genetics implies the truly complete analysis of genome interaction processes, showing that in reality that huge interaction network involves in average even all individual bases in the DNA structure, thus explaining the role and proportion of "noncoding" DNA sections and putting in strong doubt the dominating "local", or "sequential", vision of DNA operation dynamics (somehow based on the linear regime of usual computer or "Turing machine" operation) [3,8,9]. Accepting the same complex-dynamical (multivalued) approach on the unified scale of entire human organism dynamics, we arrive at the *integral medicine* paradigm, where this unreduced dynamics is explicitly presented in the form of respective dynamically probabilistic fractal in the multidimensional space of relevant variables, thus ensuring the *objectively correct*, causally complete characterization of the organism state (including interaction with the proposed treatment procedures).

Applications to superior complexity levels of *intelligent* and *conscious system* dynamics reveal the true nature of these kinds of behaviour (still missing in the unitary science framework) as high enough, well specified levels of unreduced dynamic complexity, explaining all the "special" features of these "mysterious" phenomena, with the essential role of exponentially huge efficiency of unreduced interaction dynamics [3,10,11]. The obtained general laws and features of both natural and artificial versions of intelligent and conscious behaviour create reliable guidelines for respective applications.

The rigorously substantiated *complexity principles* unified by the *symmetry of complexity* provide a practically efficient basis for all applications and include the *complexity correspondence principle* (for interacting complex systems), the *complex-dynamic control principle* (inefficiency of usual restrictive control replaced by complexity development), and the *free-interaction principle* (the above huge efficiency of unreduced interaction) [3,7,9-11]. They are particularly useful in application to *modern critical development problems*, which imply the necessity of *complexity transition* in all major spheres of life, including production processes, governance and social structure, settlement infrastructure, content and organization of science, and the new purposes of the *reason-based society* at the superior, Harmonical level of civilization complexity, the unique way of *genuine sustainability* [2,3,10,12-14].

Having started thus with the unreduced, mathematically complete analysis of arbitrary interaction process, we finally obtain, by the naturally emerging concept of creative dynamic undecidability, various problem-solving applications at different levels of real-world dynamics and the extended vision of critically important development problems, without any loss in the underlying mathematical rigour.

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